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Weatherability and Acceptance of Selected Commercial Zinc Phosphide Rodent Baits

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ABSTRACT

We evaluated the chemical and physical characteristics of five commercial zinc phosphide (Zn_3P_2) rodenticide baits at selected intervals during 16 days of exposure to prevailing weather under simulated field conditions, and conducted laboratory feeding trials to assess the effects of weathering on the acceptance and toxicity of one of the baits to Norway rats (Rattus norvegicus), *roof rats* (R. rattus), *and Polynesian rats* (R. exulans). *In bait weatherability trials, the concentration of Zn_3P_2 declined most rapidly in an oat bait that was overcoated with this toxicant. The Zn_3P_2 incorporated into pelleted formulations was less susceptible to physical weathering. All baits softened as they absorbed moisture but, with the exception of Ridall-Zinc® Field & Agricultural Bait, hardened again as they dried. Mold colonization was not apparent until after at least 4 days of exposure and occurred earlier and was more prevalent under wetter conditions. Hopkins® Zinc Phosphide Pellets were most durable in terms of retaining both their physical form and Zn_3P_2 concentration. Applying 2·5 cm of simulated rain (with or without drying) did not affect consumption of 1·0 cm Hopkins Zinc Phosphide Pellets by roof rats and Polynesian rats, but may have enhanced consumption by Norway rats. Mortality was similar among treatments for Norway rats and Polynesian rats, but was lower for roof rats offered pellets that received added moisture. Mortality for all species and treatment groups was inadequate for operational control purposes.*

INTRODUCTION

Norway rats, roof rats, and Polynesian rats cause extensive damage in Hawaiian sugarcane fields (Pemberton, 1925; Doty, 1945; Hood *et al.*, 1970; Tobin *et al.*, 1990) and macadamia orchards (Fellows, 1982; Tobin *et al.*, 1993). Currently, Zn_3P_2 is the only rodenticide registered for infield use in these crops. Historically Zn_3P_2 has been used primarily in oat groat formulations, although operationally the effectiveness of such baits has been variable [Sugihara *et al.*, 1995; Denver Wildlife Research Center (DWRC) Hawaii Field Station, unpublished reports].

Recently, increasing rat damage has prompted several Hawaiian sugarcane plantations to switch to Zn_3P_2 pellets. Laboratory studies have indicated that pelleted formulations generally are equally or more effective than oat formulations against the three species of rats in Hawaii (Tobin *et al.*, 1990; Sugihara *et al.*, 1995; DWRC Hawaii Field Station, unpublished reports). However, field applications of earlier Zn_3P_2 pelleted baits produced unsatisfactory results during previous studies by this station, presumably because of poor durability under the wet and humid conditions present in much of Hawaii. The field efficacy and weather resistance of currently available pelleted Zn_3P_2 baits have not been studied. Therefore, we exposed each of five commercial Zn_3P_2 baits under simulated field conditions and evaluated their chemical and physical characteristics after selected intervals.

The effects of weathering on the acceptance and toxicity of current Zn_3P_2 baits to rats are also unknown. Previous studies with weathered Zn_3P_2 baits offered to rodents have had conflicting results. Norway rats consumed small amounts of 5·3% Zn_3P_2 tablets that had been weathered for 2 days, and none died (DWRC Hawaii Field Station, unpublished report). The relatively high concentration of Zn_3P_2 may have diminished bait acceptance and reduced mortality. In laboratory bioassays with pine voles (*Microtus pinetorum*), moist ZP® Rodent Bait AG pellets were as acceptable and effective as dry pellets (Merson & Byers, 1985). Hayne (1951) found that the toxicity of Zn_3P_2-treated cracked corn to albino laboratory mice (*Mus musculus*) declined with increased weathering, but he did not report the effects on consumption except to note that undiluted, less weathered baits were repellent to some mice. To evaluate the effects of weathering on bait acceptance and toxicity, we exposed a commercial Zn_3P_2 bait to three weathering regimes and offered the bait to each of the three species of rats in Hawaii during a single 24 h laboratory feeding trial.

MATERIALS AND METHODS

Bait weatherability trials

Baits

We evaluated five commercial Zn_3P_2 baits: ZP Rodent Bait AG (Bell Laboratories, Inc., 1·0 cm diameter, 2·0% ai), two sizes of Hopkins Zinc Phosphide Pellets (HACCO, Inc., 1·0 and 0·5 cm diameter, 2·0% ai), Ridall-Zinc Rodent Field & Agricultural Bait (LiphaTech, Inc., 0·5 cm diameter, 1·88% ai), and KFE Zinc Phosphide Prepared-Rat Bait® (Kawamura Farm Enterprises, Inc., 1·88% ai) (reference to commercial products is for identification only and does not imply endorsement by the authors or the US Department of Agriculture). All except the last bait were pelleted formulations; the KFE bait was formulated on oat groats.

Test substrate

We filled plastic nursery flats (52·3 × 26·3 × 6·3 cm) to a depth of 5 cm with Hilo silty clay loam collected from recently harvested sugarcane fields and sifted through 0·6 cm mesh hardware cloth. Flats were placed outdoors on 4·0 cm-high wooden slats for drainage. We spread a thin layer of Pest Barrier Tree Tanglefoot® (The Tanglefoot Company) on the inside walls of each flat above the soil level to exclude crawling invertebrates, and covered each row of flats with 2·5 cm poultry wire to exclude birds and other animals.

Experimental design

We conducted two trials using the same procedures except as noted. During trial one, 30 flats were arranged in six rows of five flats each. We evenly distributed 30 g of bait on the soil in each flat, with each bait randomly assigned to one flat within each column and row in a 5 × 5 Latin square design and to one flat in the sixth row.

During trial two, we did not evaluate the 0·5 cm Hopkins pellets. We evenly distributed 30 g of bait on the soil in each of 28 flats, with each of the remaining four baits randomly assigned to one flat within each column (four) and row (seven) using a double 4 × 4 Latin square arrangement with one randomly selected row deleted.

Data collection and analysis

Sample collection and exposure periods—We collected about one-sixth of the bait on each flat immediately after exposing the baits (t_0) and on each of days one (t_1), two (t_2), four (t_4), eight (t_8), and 16 (t_{16}). A plastic spoon and a metal spatula were used to lift the bait from the soil. The metal spatula was also used to remove any soil adhering to the baits. All samples were collected at approximately the same time of day. Rain was recorded daily.

Physical characteristics—We visually examined each sample and recorded obvious changes in physical characteristics (e.g. shape, swelling, cracking, color, disintegration, presence of mold), as well as the proportion of the sample affected. We used a Stokes Tablet Hardness Tester® to measure the amount of pressure required to break each of 10 pellets of each pelleted bait. Hardness was recorded as zero for pellets that were too soft to measure or disintegrated when touched.

Chemical analysis—On each sampling day, the samples of each bait were pooled and dried in a mechanical convection oven at 100°C for 3 h, bagged, labelled, and immediately frozen at −20°C. At the conclusion of each trial, samples were shipped by air to the DWRC Analytical Chemistry Section (ACS) for analysis of Zn_3P_2 content.

All samples except the oats were ground to ensure complete hydrolysis during Zn_3P_2 analysis. Samples were dried in an oven at 100°C for 1 h and cooled in a desiccator before weighing to remove variability resulting from differing moisture conditions among sampling periods. Zn_3P_2 concentration (w/w) was determined by reacting triplicate 1 g portions of each dehydrated bait in a 30% sulfuric acid solution and performing headspace analysis on a Hewlett-Packard Model 5880 gas chromatograph (Analytical Method 29A: Zinc Phosphide Bait Assay, available from DWRC ACS, Denver, CO).

The use of dehydrated samples precluded direct comparisons with the Zn_3P_2 concentrations stated on the registration labels. We evaluated changes in Zn_3P_2 concentration relative to the concentration at t_0 using the mean of the ratios of the concentrations in the three 1 g portions at each time interval (t_x) to the mean concentration in the three 1 g portions at time zero (t_0).

Statistical analyses—We performed separate ANOVAs for each trial to evaluate whether the concentration of Zn_3P_2 remaining and pellet hardness varied among baits and over time (SAS Institute Inc., 1988). We performed linear regressions to examine the effects of length of exposure, cumulative rain and rain during the 24 h prior to sampling on the concentration of Zn_3P_2 remaining and pellet hardness (SAS Institute Inc., 1988). We evaluated significance at $p \leqslant 0{\cdot}05$ for the ANOVAs, and at $p \leqslant 0{\cdot}05$ and $r^2 \geqslant 0{\cdot}50$ for the regressions.

Bait acceptance trials

Animal procurement and maintenance

Norway, roof, and Polynesian rats were captured in and around sugarcane fields and forested areas near Hilo (HI) and quarantined at the

DWRC Hawaii Field Station for a minimum of 14 days before testing. Rats were maintained in individual stainless steel cages ($18 \times 18 \times 36$ cm) with *ad libitum* supplies of Rodent Laboratory Chow. 5001® (Purina Mills, Inc.) and water. Quarantine and test rooms were maintained at about 23–26°C with a 12 h light : dark cycle.

Seven males and seven females of each species were randomly assigned from weight groups to each of three treatments and transferred to the test room. Only healthy Norway rats and roof rats weighing $\geqslant 90$ g and Polynesian rats weighing $\geqslant 35$ g were used.

Treatments

We evaluated the acceptance and efficacy of Hopkins Zinc Phosphide Pellets that had been exposed to three simulated weathering regimes. Nine nursery flats prepared as for the weatherability trials were arranged in three rows of three flats under an outdoor awning. We randomly assigned one weathering regime to each row and evenly distributed 200 g of bait on the soil in each flat. Bait in treatment 1 (dry) received no added moisture during the exposure period. We sprinkled 2·5 cm of tapwater over the bait in each flat in treatments 2 (wet) and 3 (wet and dried), in four 0·625 cm applications at 2 h intervals to simulate rain. We covered each row of flats with 2·5 cm poultry wire to exclude birds and other animals. Twenty-four hours later, we collected the bait from each flat and pooled the bait for each treatment. Adhering soil particles were removed with a small brush. Pellets for treatment 3 were dried for 2 h in a convection oven at 85°C, and then cooled to room temperature in a desiccator.

One 20 g bait sample from each treatment and an unexposed control were dried in a convection oven at 100°C for 3 h, cooled, frozen at −20°C, and sent to the DWRC ACS for analysis of Zn_3P_2 concentration (Analytical Method 29A: Zinc Phosphide Bait Assay). Zn_3P_2 concentrations were based on the mean of three 1 g portions of each treatment and were expressed as $\%Zn_3P_2/g$ dehydrated bait.

Feeding trial

We offered each rat four pellets (approximately 5 g unexposed weight) of its assigned treatment in a 24-h, no-choice feeding trial. We removed the maintenance laboratory chow during the trial and placed a tray under each cage to collect spillage. Water was available *ad libitum* throughout the study. We observed the animals daily for mortality or signs of toxicosis during the trial and for 10 days post-treatment. Carcasses were disposed of at the Hawaii County animal disposal site.

Data analysis
We calculated consumption by adjusting the amount of bait offered for moisture gain or loss (based on changes in the weight of five samples/treatment that were exposed in the test room during the trial) and subtracting the weight of uneaten and spilled food. We performed a separate ANOVA for each species to compare percentage consumption (expressed as a percentage of the amount of bait offered) among treatment groups (SAS Institute Inc., 1988). We performed χ^2 tests to evaluate mortality (SAS Institute Inc., 1988c). We evaluated significance at $p \leqslant 0{\cdot}05$ for all tests.

RESULTS

Bait weatherability trials

Precipitation
During trial 1, almost 1 cm of rain fell during the 24 h preceding t_1, and more than half of the total cumulative precipitation fell between t_4 and t_8 (Fig. 1). More than 1·6 cm of rain fell during trial 2, but only 0·11 cm was recorded between t_0 and t_8 (Fig. 1).

Percentage of initial Zn_3P_2 remaining
The percentage of the initial (t_0) concentration of Zn_3P_2 remaining varied among baits over time (trial 1—$F_{\text{interaction}} = 7{\cdot}83$; d.f. = 20,60; $p = 0{\cdot}0001$, trial 2—$F_{\text{interaction}} = 1{\cdot}97$; d.f. = 15,48; $p = 0{\cdot}041$).

In trial 1, the large and small Hopkins Zinc Phosphide Pellets still had 100 and 97%, respectively, of their original Zn_3P_2 concentration at t_{16} (Table 1), which suggests that pellet size did not affect retention of Zn_3P_2. Ridall-Zinc Field & Agricultural Bait retained 99% of its Zn_3P_2 through t_4, and at t_8, still had almost 90% of the Zn_3P_2 present at t_0. The concentration of Zn_3P_2 in ZP Rodent Bait AG declined by 16% during the first 24 h of exposure and generally fluctuated between 80 and 88% during the remainder of the trial. The decline from the initial Zn_3P_2 concentration was most pronounced in the KFE Zinc Phosphide Prepared-Rat Bait; 15% by t_1 and > 50% by t_{16}.

In trial 2, all three pelleted baits retained > 90% of their initial Zn_3P_2 concentrations through t_8, and Hopkins and Ridall-Zinc baits retained > 90% through t_{16} (Table 1). KFE prepared-rat bait retained 78% of its original Zn_3P_2 concentration at t_2, and 75% at t_{16}.

Reductions in the Zn_3P_2 concentration of pelleted baits generally were relatively small, particularly during the drier second trial, and had little or no association with the weather/exposure factors we evaluated. When

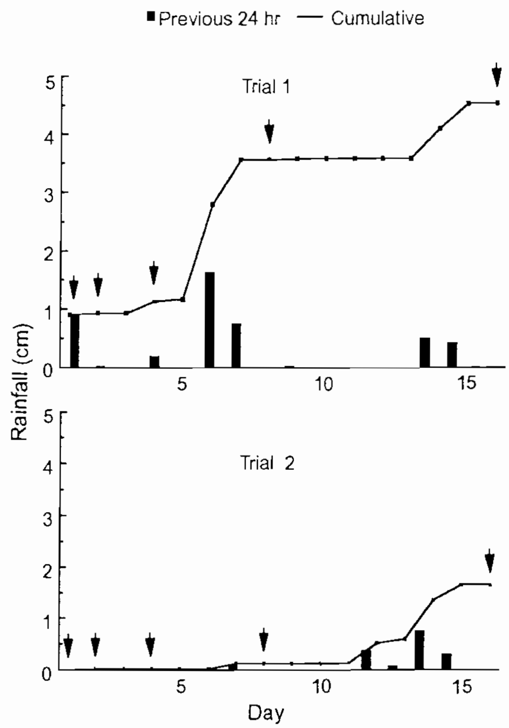

Fig. 1. Recent and cumulative rain during simulated field trials with commercial Zn_3P_2 baits. Arrows indicate days when bait samples were collected.

declines were more substantial, the cumulative aspects of weathering (length of exposure and cumulative rain) were most associated with the loss of Zn_3P_2 from pelleted baits. This was true for Ridall-Zinc pellets during trial 1 (length of exposure, $r^2 = 0{\cdot}68$, $p = 0{\cdot}0001$; cumulative rain, $r^2 = 0{\cdot}64$, $p = 0{\cdot}0001$) and ZP Rodent Bait AG during trial 2 (length of exposure, $r^2 = 0{\cdot}74$, $p = 0{\cdot}0001$; cumulative rain, $r^2 = 0{\cdot}61$, $p = 0{\cdot}0001$), but not for any other pelleted bait (length of exposure, $r^2_{\text{trial 1}} \leqslant 0{\cdot}02$, $r^2_{\text{trial 2}} \leqslant 0{\cdot}30$; cumulative rain, $r^2_{\text{trial 1}} \leqslant 0{\cdot}06$, $r^2_{\text{trial 2}} \leqslant 0{\cdot}13$).

Loss of Zn_3P_2 was greatest in the oat bait in both trials, and was associated with cumulative rain and to a lesser extent length of exposure during trial 1 (cumulative rain, $r^2 = 0{\cdot}75$, $p = 0{\cdot}0001$; length of exposure, $r^2 = 0{\cdot}67$, $p = 0{\cdot}0001$), but not during trial 2 (cumulative rain, $r^2 = 0{\cdot}13$, $p = 0{\cdot}14$; length of exposure, $r^2 = 0{\cdot}19$, $p = 0{\cdot}07$).

Precipitation during the 24 h preceding each sampling was not associated with the percentage of initial Zn_3P_2 concentration remaining in any bait in either trial ($r^2_{\text{trial 1}} \leqslant 0{\cdot}23$, $r^2_{\text{trial 2}} \leqslant 0{\cdot}26$).

Physical characteristics

Pellet hardness varied among baits over time (trial 1 — $F_{\text{interaction}} = 22{\cdot}10$; d.f. = 15,216; $p = 0{\cdot}0001$; trial 2 — $F_{\text{interaction}} = 13{\cdot}80$; d.f. = 10,162;

TABLE 1
Mean Percentage (SE) of the Initial Zn_3P_2 Concentration Remaining[a] in Rodenticide Baits Exposed Under Simulated Field Conditions

Trial	t_x (*day*)	*ZP Rodent Bait AG*[b]	*Large Hopkins pellets*[c]	*Bait* *Small Hopkins pellets*[c]	*Ridall-Zinc*[d]	*KFE oats*[e]
1	0	99·9 (2·7)	100·0 (2·0)	99·8 (1·9)	99·8 (2·8)	99·7 (12·9)
	1	84·1 (1·0)	105·7 (0·9)	99·8 (2·8)	106·0 (2·6)	84·6 (5·5)
	2	82·9 (1·1)	91·7 (1·8)	92·1 (0·9)	105·2 (3·3)	89·9 (5·3)
	4	70·5 (3·8)	101·0 (1·1)	100·3 (1·3)	98·5 (4·5)	82·1 (5·4)
	8	80·0 (0·7)	104·0 (1·5)	107·7 (1·8)	89·7 (1·8)	58·5 (1·2)
	16	87·9 (0·7)	100·7 (1·1)	96·9 (2·6)	83·3 (2·0)	49·6 (6·2)
2	0	99·9 (1·1)	100·0 (2·9)		99·9 (1·1)	99·8 (5·9)
	1	96·7 (0·7)	100·5 (1·3)		93·8 (1·8)	88·2 (5·5)
	2	95·1 (1·3)	102·2 (2·7)		98·0 (2·8)	78·2 (5·4)
	4	92·0 (1·4)	102·1 (1·5)		89·5 (1·5)	79·6 (3·2)
	8	93·4 (1·5)	91·4 (0·3)		93·5 (2·3)	85·6 (6·7)
	16	85·3 (1·7)	95·3 (1·7)		93·6 (1·0)	75·0 (7·6)

[a]Percent Zn_3P_2 at $t_x = (Zn_3P_2$ concentration at t_x/mean concentration at $t_0) \times 100$.
[b]ZP Rodent Bait AG (Bell Laboratories Inc., 1·0 cm diameter, 2·0% ai).
[c]Hopkins Zinc Phosphide Pellets (HACCO Inc., 1·0 and 0·5 cm diameter, 2·0% ai). The 0·5 cm pellets were not included in trial 2.
[d]Ridall-Zinc Rodent Field & Agricultural Bait (LiphaTech Inc., 0·5 cm diameter, 1·88% ai).
[e]KFE Zinc Phosphide Prepared-Rat Bait (Kawamura Farm Enterprises Inc., 1·88% ai).

$p = 0.0001$). In both trials, the pelleted baits swelled and softened when they got wet, and all except Ridall-Zinc pellets hardened again as they dried (Table 2). Ridall-Zinc pellets lost their form and deteriorated rapidly after initial exposure to moisture, and thereafter remained fragile and never regained their original hardness. All other pelleted baits remained intact at the conclusion of the trials, although those in trial 2 were still soft from recent rains. Hardness of the KFE oat bait could not be measured, but visual and tactile inspection indicated that the oats swelled and softened with rain, and in the absence of moisture subsequently dried and hardened.

During trial 1, hardness of the 0·5 cm Hopkins pellets declined when rain occurred during the 24 h prior to sampling ($r^2 = 0.58$, $p = 0.0001$). Otherwise there was little or no linear relationship for any bait between pellet hardness and length of exposure ($r^2 \leqslant 0.20$), cumulative rain ($r^2 \leqslant 0.09$), or rain during the 24 h prior to sampling ($r^2 \leqslant 0.36$).

During trial 2, the hardness of ZP Rodent Bait AG and Hopkins pellets declined as length of exposure (ZP Rodent Bait AG—$r^2 = 0.54$, $p = 0.0001$; Hopkins pellets—$r^2 = 0.50$, $p = 0.0001$) and cumulative rain (ZP Rodent Bait AG—$r^2 = 0.74$, $p = 0.0001$; Hopkins pellets—$r^2 = 0.62$, $p = 0.0001$) increased. This probably reflects that little rain fell until just prior to the final sampling. The hardness of ZP Rodent Bait AG also declined when rain occurred during the 24 h preceding sampling ($r^2 = 0.61$, $p = 0.0001$). Otherwise, there was little or no linear relationship between these variables and pellet hardness (length of exposure $r^2 = 0.43$, cumulative rain $r^2 = 0.18$, rain during the 24 h preceding sampling $r^2 \leqslant 0.47$).

That the weather/exposure factors we evaluated had little or no association with the hardness of Ridall-Zinc pellets probably reflects that these pellets deteriorated rapidly and remained soft and crumbly regardless of the conditions. The effect of rain during the 24 h prior to sampling may have been obscured because hardness was measured only at selected intervals, and both rain and suspected periods of bait softening and hardening occurred between sampling.

In both trials, mold grew primarily on the side of the baits that touched the soil. Mold was not visible on any bait sample until t_8 during trial 1 (when 10% of the ZP Rodent Bait AG, 45% of the 1·0 cm Hopkins pellets, 25% of the 0·5 cm Hopkins pellets, 20–25% of the KFE oats, and 15% of the Ridall-Zinc pellets were affected), and until t_{16} during the drier second trial (when 0% of ZP Rodent Bait AG, 55% of 1·0 cm Hopkins pellets, 5% KFE oats, and 5% of Ridall-Zinc pellets were affected). By t_{16} of trial 1, 100% of the ZP Rodent Bait AG and both sizes of the Hopkins pellets, 75–80% of the KFE oats, and 90–95% of the Ridall-Zinc pellets were moldy.

TABLE 2

Mean Hardness (kg) (SE) of Pelleted Rodenticide Baits Exposed under Simulated Field Conditions

Trial	t_x (*day*)	*Bait*: *ZP Rodent Bait AG*[a]	*Large Hopkins pellets*[b]	*Small Hopkins pellets*[b]	*Ridall-Zinc*[c]
1	0	7·3 (0·5)	9·3 (0·6)	4·8 (0·3)	2·4 (0·5)
	1	0·0 (0·0)	0·0 (0·0)	0·0 (0·0)	0·3 (0·1)
	2	0·4 (0·4)	3·1 (0·7)	5·3 (0·3)	0·6 (0·1)
	4	9·1 (0·3)	7·9 (0·6)	3·6 (0·4)	0·6 (0·0)
	8	5·3 (1·2)	5·6 (0·5)	3·1 (0·3)	0·8 (0·1)
	16	8·8 (0·6)	4·7 (0·5)	3·0 (0·3)	0·6 (0·1)
2	0	8·2 (0·4)	9·2 (0·8)		4·1 (0·4)
	1	9·2 (0·5)	10·4 (0·7)		3·9 (0·4)
	2	6·0 (0·3)	7·2 (0·7)		0·8 (0·1)
	4	10·0 (0·5)	10·3 (0·8)		0·6 (0·1)
	8	8·6 (0·7)	8·7 (0·7)		0·3 (0·1)
	16	0·0 (0·0)	1·4 (0·4)		0·0 (0·0)

[a] ZP Rodent Bait AG (Bell Laboratories Inc., 1·0 cm diameter, 2·0% ai).
[b] Hopkins Zinc Phosphide Pellets (HACCO Inc., 1·0 and 0·5 cm diameter, 2·0% ai). The 0·5 cm pellets were not included in trial 2.
[c] Ridall-Zinc Rodent Field & Agricultural Bait (LiphaTech, Inc., 0·5 cm diameter, 1·88% ai).

Bait acceptance trials

The mean concentration of Zn_3P_2 per gram of dehydrated bait was 2·15% for the unexposed bait, 2·24% for the unmoistened bait, 1·76% for the moistened bait, and 1·84% for the moistened and dried bait. Zn_3P_2 concentration expressed as a percentage of the mean concentration of the unexposed bait was 104% for the unmoistened bait, 82% for the moistened bait, and 86% for the moistened and dried bait.

Percent consumption by Norway rats varied among treatments ($F = 4{\cdot}03$; d.f. = 2,39, $p = 0{\cdot}03$) and was less for the group offered dry pellets than for groups offered pellets that were moistened, whether or not the pellets were subsequently dried (Table 3). Mortality varied from 14 to 29% and was similar among the three groups ($\chi^2 = 1{\cdot}05$; d.f. = 2, $p = 0{\cdot}59$). Percent consumption by roof rats did not vary among treatments ($F = 1{\cdot}43$; d.f. = 2,39, $p = 0{\cdot}25$), but mortality was highest (71%) for the group offered the dry bait ($\chi^2 = 5{\cdot}96$; d.f. = 2, $p = 0{\cdot}05$) (Table 3). Both percentage consumption ($F = 0{\cdot}28$; d.f. = 2,39, $p = 0{\cdot}76$) and mortality ($\chi^2 = 0{\cdot}58$; d.f. = 2, $p = 0{\cdot}75$) were similar among the three groups of Polynesian rats (Table 3). Mortality of Polynesian rats varied from 36 to 50%.

DISCUSSION

Baiting programs with acute rodenticides like Zn_3P_2 should result in good initial bait consumption and rapid population declines. Mortality with Zn_3P_2 occurs within 72 h, by which time surviving rats drastically reduce or cease their consumption of the Zn_3P_2 bait (Tobin *et al.*, 1990; Shepherd & Inglis, 1993; Sugihara *et al.*, 1995). Thus, Zn_3P_2 baits should maintain their toxicity and palatability for a few days and then break down rapidly to reduce potential environmental hazards. Bait availability beyond 2 or 3 days may provide protection against invading rats, but it is not likely to enhance control of resident populations and may increase the exposure of nontarget animals to the bait. Baits that deteriorate in less than 2 or 3 days may result in sublethal consumption of Zn_3P_2 and the development of bait shyness, which would reduce the effectiveness of subsequent Zn_3P_2 baiting programs.

In our study, all pelleted baits except ZP Rodent Bait AG under wetter conditions retained $\geqslant$90% of their original (t_0) Zn_3P_2 concentrations through at least t_4; the KFE oat bait lost its active ingredient much more rapidly. Physical weathering, particularly rain, is the factor most often associated with loss of Zn_3P_2 from grain baits (Elmore & Roth, 1943;

TABLE 3
Mean Percent Consumption (SE) and Mortality in Hawaiian Rats Offered Weathered Zn_3P_2 Pelleted Bait During One 24 h Feeding Trial

Bait[a]	*% ai*[b]	*Initial body weight (g)*	*Consumption*[c]			*No. died/ no. tested*
			All rats	*Mortalities*	*Survivors*	
Rattus rattus						
Dry	2·24	164	10·6 (3·6)	14·6 (4·5)	0·8 (0·8)	10/14
Wet	1·76	161	7·6 (2·0)	16·5 (2·8)	4·1 (1·4)	4/14
Wet and dried	1·84	166	15·1 (3·6)	21·6 (2·6)	11·5 (5·1)	5/14
Rattus norvegicus						
Dry	2·24	204	7·1 (2·1)	17·4 (4·2)	3·0 (0·6)	4/14
Wet	1·76	204	14·3 (2·6)	27·9 (13·7)	12·0 (1·8)	2/14
Wet and dried	1·84	201	15·8 (2·1)	22·1 (4·9)	13·2 (1·8)	4/14
Rattus exulans						
Dry	2·24	783	4·0 (0·8)	6·4 (0·5)	1·6 (0·5)	7/14
Wet	1·76	74	4·2 (1·5)	7·1 (2·2)	2·0 (1·6)	6/14
Wet and dried	1·84	73	5·4 (2·0)	14·0 (2·7)	0·7 (0·2)	5/14

[a] Hopkins Zinc Phosphide Pellets (HACCO Inc., 1·0 cm diameter) exposed under selected weathering regimes. The wet and wet and dried treatments received 2·5 cm simulated rain.
[b] Determined using gas chromatography and expressed as $\%Zn_3P_2$/g dehydrated bait.
[c] Calculated as (g of bait consumed/g of bait offered) × 100.

Hayne, 1951; Hilton & Mee, 1972; Hilton *et al.*, 1972; West *et al.*, 1972), although Hilton *et al.* (1972) found that limited chemical decomposition may occur in wet or deteriorating bait. Physical weathering was probably the primary route of Zn_3P_2 loss for the oat bait in our test; the acidic soil (pH = 5·6 trial 1, pH = 6·3 trial 2) may have expedited the breakdown of the Zn_3P_2. The slower loss of Zn_3P_2 from the pelleted baits suggests that formulations that incorporate Zn_3P_2 throughout are less susceptible to toxicant loss by physical weathering than are baits overcoated with Zn_3P_2.

All baits except Ridall-Zinc retained their form throughout the study, softening when they absorbed moisture and hardening as they dried. Askham (1985) found that the hardness of ZP Rodent Bait AG pellets diminished rapidly when they were exposed to 0·4–12·7 mm of simulated precipitation, but he did not report the condition of pellets that dried. We have found no other published studies on the weatherability of the pellets evaluated in this study.

Soil moisture probably contributed to the loss of bait hardness and retarded drying. During the 65 min that elapsed while the baits were applied and collected for the t_0 sample in trial 1, approximately 75% of Ridall-Zinc pellets became moist and slightly swollen on the side in contact with the soil, which was damp from the 0·15 cm of rain that fell during the previous night. The other pellets remained firm and did not swell, but some had damp spots where they touched the soil. The susceptibility of the Ridall-Zinc bait to moisture may partially reflect the large surface area to volume ratio of these small-diameter pellets.

Few studies have evaluated the effect of mold on bait palatability. Sanchez *et al.* (1973) found that *Rattus r. mindanensis* consumed similar amounts of rice, whether it was dry, soaked or moldy. Rebar and Reichman (1983) determined that rock pocket mice (*Perognathus intermedius*) consumed similar amounts of nonmoldy seeds and seeds in the early stages of mold colonization, but consumed less of extremely moldy seeds. In our study, mold was not visible on any bait until after 4 days of exposure, indicating that it probably has little effect on bait consumption during the critical early days of operational baiting programs. However, more study is needed to verify the effects of mold on the acceptance of Zn_3P_2 baits by rats.

During the bait acceptance trials, simulated rain had little effect on consumption. Norway rats offered moistened bait actually consumed more than did those offered unmoistened bait. Consumption of moistened and unmoistened bait was similar for both roof rats and Polynesian rats.

Mortality for all three species was lower than in previous studies with unweathered Hopkins pellets (Tobin *et al.*, 1990; Sugihara *et al.*, 1995), and in most cases was not affected by moisture. The higher mortality of roof rats offered the dry bait may have been due to the higher concentration of Zn_3P_2 in this bait.

Most of the pelleted formulations retained their active ingredient and physical form, and did not mold for $\geqslant 4$ days. The exception was Ridall-Zinc, which deteriorated rapidly under wet conditions. The KFE Zinc Phosphide Prepared-Rat Bait also maintained its physical form and did not mold for at least 4 days, but this oat formulation was the most susceptible to loss of Zn_3P_2 of the baits we evaluated.

Whether changes in bait acceptability can account for the variable results obtained with pelleted baits under field use is less clear. For all three species, consumption of Hopkins Zinc Phosphide Pellets was not affected by exposing the bait to simulated rain. However, none of the treatments produced levels of mortality that were adequate for operational control programs.

SUMMARY

We evaluated the chemical and physical properties of five commercial Zn_3P_2 rodenticide baits at selected intervals during 16 days of exposure to simulated field conditions, and conducted laboratory bioassays to evaluate the effects of weathering on the acceptance and toxicity of one of the pelleted baits to each of three species of rats in Hawaii. Four pelleted formulations that were impregnated with Zn_3P_2 retained their toxicant better than an oat formulation that was overcoated with Zn_3P_2. Hopkins Zinc Phosphide Pellets retained both their physical form and the toxicant best under the conditions of this study. All baits softened when they absorbed moisture, but most hardened again as they dried. Ridall-Zinc pellets remained crumbly after their initial exposure to moisture. Mold colonization was not evident until after at least 4 days of exposure and was more prevalent under wetter conditions. In laboratory feeding trials, exposure of Hopkins Zinc Phosphide Pellets to simulated rain had little effect on consumption by roof rats and Polynesian rats; Norway rats increased their consumption of moistened bait. Low mortality in all species and treatment groups indicates that benefits of operational use of Hopkins Zinc Phosphide Pellets could be less than satisfactory.

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